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*Research article*

## **A systematic literature review of quantitative models for sustainable supply chain management**

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**Abstract:** Supply chain management is the basis for the execution of operations, being considered as the core of the business function in the 21st century. On the other hand, at present, factors such as the reduction of natural resources, the search for competitive advantages, government laws and global agreements, have generated a greater interest in the sustainable development, which, in order to achieve it, industries need to rethink and plan their supply chain considering a path of sustainability. So sustainable supply chain management emerges as a means to integrate stakeholders' concern for profit and cost reduction with environmental and social requirements, attracting significant interest among managers, researchers and practitioners. The main objective of this study is to provide a synthesis of the key elements of the quantitative model offerings that use sustainability indicators in the design and management of forward supply chains. To achieve this objective, we developed a systematic literature review that includes seventy articles published during the last decade in peer-reviewed journals in English language. In addition a 4 Ws analysis (When, Who, What, and Where) is applied and three structural dimensions are defined and grouped by categories: Supply chain management, modeling and sustainability. As part of the results we evidenced a continuous growth in the scientific production of this type of articles, with a predominance of deterministic mathematical programming models with an environmental economic perspective. Finally, we identified research gaps, highlighting the lack of integral inclusion of a life cycle analysis in the design of supply chain networks.

**Keywords:** sustainable supply chain management; sustainability; systematic literature review; quantitative models supply chain; forward supply chain

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## 1. Introduction

Supply chain management (SCM) has now become the basis for executing operations, being regarded as the core of the business function in the 21st century [1]. According to [2] well-structured supply chains (SC) become strategic tools that help companies generate competitive advantages in today's market. Additionally, the interest in reducing environmental impact has caused governments and consumers to demand and pressure companies to be aware of and, above all, to reduce the pollution generated by their products and industrial processes [3]. To address these needs, especially during the last few years, sustainable supply chain management (SSCM) attracts significant attention among managers, researchers and practitioners [4].

The World Commission on Environment and Development (WCED) defines and maintains that sustainable development is capable of meeting the needs of the present generation without compromising the ability of the future generation to meet its own needs [5]. The inclusion of sustainable development in our lives and activities will become the only way to solve most of the global problems that exist today, such as climate change, water scarcity, inequality, poverty, hunger, among others [6].

As a result, companies are constantly researching new methods and strategies to make their operations sustainable. Research includes the use of renewable energy, development of environmentally friendly raw materials, green procurement, selection of green suppliers, reduction of plastic packaging, development of closed-loop supply chains (CLSC), reduction of carbon and greenhouse gas emissions, remanufacturing, reverse logistics, among others [7].

These strategic decisions are the basis for the development of a sustainable supply chain network (SSCN) design, which is characterized by finding the best location of facilities, capacities and flow between them, maximizing economic and social performance while minimizing environmental impact [8].

SSCM has always encouraged researchers to generate scientific output, initially based on environmental indicators, in addition to classical economic considerations. After a few years, studies began to timidly include social indicators, but it was not until 1994 that the concept of the “triple bottom line” was first introduced by [9], which seeks to balance the three dimensions of business: economic, environmental and social.

In other literature review, it is mentioned that in the last two decades there has been a considerable growth in the number of studies conducted on SSCM, empirical studies, conceptual models and formal quantitative models highlighting [10]. A formal quantitative model, unlike the others, is based on a set of strategies that allow obtaining and processing information through statistics and formal numerical techniques that are framed within a cause-effect relationship [11]. Quantitative models have been more used in CLSC, therefore there are several review articles focused on these aspects [12]. A recent and exhaustive review of [13] shows that there are few studies looking at quantitative methods and the forward SC, recent works such as [14] demonstrate the importance of filling this gap and carry out a detailed review of the latest quantitative models applied in the forward SC that allow obtaining sustainability.

SC sustainability can be improved from multiple approaches, therefore, this paper helps to visualize and understand some models used in the past and present to improve this area. Consequently, the main objective of this study is to provide a synthesis of the key elements of the quantitative model

offerings that use sustainability indicators in the design and management of forward SC in order to finally identify trends, gaps and lessons in the selected literature.

Studies such as this one guide companies and researchers to understand the current lines of research, the models being used and the solution approaches applied to find optimal and innovative results in terms of sustainability. For a better understanding, the document is structured as follows: Section 2 explains key concepts on SC and sustainability, and an overview of literature reviews. Section 3 describes the methodology used to collect and analyze the literature. Section 4 presents the research findings by the content analysis and identifies directions for future research. Section 5 provides a brief discussion. And finally, Section 6 synthesizes the main conclusions.

## **2. Theoretical foundation and literature reviews**

### *2.1. Supply chain management*

The main elements that make up a SC are suppliers, plants, distribution centers, retailers and customers, whose main function is to acquire raw materials, process them and distribute the finished products to customers. Then SC network (SCN) design optimizes the configuration of all these elements in order to minimize total costs while meeting service levels [15], is an area of decision making that considers parameters such as planning, costs, demand and supply.

The decisions that guide an SCN design are born at a strategic and tactical management level [8], are usually made in the long term due to their importance and have an immediate impact on the performance of an SC [16].

In our study, two types of SC configuration are mentioned, forward SC and CLSC, the first, also known as traditional SC deals with the flow of products from raw materials to the manufacturer, to the retailer, and finally to the consume [17], instead a CLSC according to [18] essentially combines the traditional supply chain with reverse logistics, considering the item after its served its original purpose, the manufacturer works to encourage the items return once its no longer functional or needed and the items can either be repaired and resold, or they can be broken down for reuse in future products.

SCM, therefore, encompasses a management of each and every one of the links that are generated between the elements of a SC [19], these links include in their flows physical, financial and informational variables that must be managed jointly among all participants [20].

### *2.2. Sustainable supply chain management*

The Dow Chemical Company says sustainability is about making every decision with the future in mind. The probability of a company's success improves with the implementation of sustainability [21] and its application in all its activities, considering not only economic, but also environmental and social variables.

The three basic dimensions of sustainable development are: economic, social and environmental, a concept known as triple bottom line (TBL), industries wishing to achieve this result must have the capacity and commitment to design, plan and operate their SC based on sustainability requirements, without compromising resources of other stakeholders [22]. The main obstacle is the level of complexity that this represents, as it involves several products, suppliers, materials, capabilities and other variables.

SSCM has been created in order to integrate two general concerns that arise in the participants of a supply chain, obtaining the greatest amount of profit and reducing the environmental and social impact of operations [23]. Other authors define SSCM as “the management of flows of products, material, money and information, as well as cooperation between SC elements, considering the objectives of the three dimensions of sustainable development (environmental, social and economic) arising from customer and stakeholder requirements” [24].

Professionals, technicians, managers and researchers use the word SSCM more frequently today [25], investing large amounts of resources in the development and implementation of sustainability, highlight the importance of an SSCM and value its role by adjusting to different business needs, in addition to raising awareness about sustainable practices such as the selection of green suppliers, ethical sourcing, products with carbon footprints, social responsibility, etc. [26].

### 2.3. Literature reviews

In recent years, a significant number of literature review articles have been published on the various topics covered by SSCM. We can find systematic and narrative reviews. Systematic literature reviews involve a methodical process composed of structured steps to collect and analyze the material found; this type of literature review is considered exhaustive, objective, valid, verifiable and reproducible [27]. Narrative reviews, on the other hand, depend mainly on the experience of the researchers, the surveys that are applied and a less formal scheme [28].

To get an idea of the amount of literature reviews on April 8, 2020, a search was performed in the Science Direct database with the following equation “sustainable supply chain management” AND “literature review” yielding 826 articles, which is evidence that these types of articles are currently an abundant resource that allows researchers to know the state of the art regarding sustainability in SC and guide their current and future research.

According to [13] in their study of 198 literature reviews, it shows that this type of work is undergoing a change with respect to methodology, the majority of reviews have gone from being narrative to systematic. Evidence the majority of literature reviews include conceptual models and formal models. Regarding formal models, studies in CLSC stand out [18], and conversely, there are few reviews of formal models in forward SC [25]. The literature of SSCM studies multiple viewpoints, from focal firms [29], to particular country profiles [30], or segments of the population [31].

From the beginning and for many years the environmental perspective dominated sustainability research, but now it is changing, TBL is the new approach that most works try to include. Some highlights are as follows: sustainable supply chain management [32], green supply chain [4], sustainable supply chain network design [10], dynamics modeling for sustainable supply chain management [33], sustainable supply chain finance [34], sustainable network design under uncertainty [7].

The environmental perspective covers various topics such as greenhouse gas emissions, pollution, CO<sub>2</sub> emissions, natural resources, energy and others. As for the social variables included in the studies, we have training, worker safety, ethical SC, social justice, decent work and fair treatment.

### 3. Methodology

This article performs a systematic literature review on SSCM focusing on the use of formal quantitative models in forward SSC, for its correct execution, decision making, quality, consistency and procedures to follow, we rely on the work and methodologies of two authors, Seuring [35] and Fink [27]. Together they will allow us to collect the appropriate information and analyze its content in a structured way.

Therefore, our literature review will consist of 4 general steps: 1) material collection, 2) descriptive analysis, 3) category identification and 4) material evaluation [35]. To obtain and filter the optimal material for step 1, four tasks of the Fink methodology [27] will be followed: 1) selection of research questions, 2) definition of database sources, 3) selection of search terms, and 4) application of practical inclusion and exclusion criteria.

#### 3.1. Material collection

The following four steps, taken from Fink's methodology, will allow us to collect and filter quality articles related to our study.

##### 3.1.1. Selection of research questions

The research questions guiding our systematic literature review are:

- What quantitative models have been applied in the effective management of a forward SC considering sustainability indicators?
- What characteristics, indicators, solution approaches are used in these quantitative models?
- How these quantitative models have supported sustainability decisions?

##### 3.1.2. Definition of database sources

The database sources to be used in the literature review are:

- Scopus
- ScienceDirect
- SpringerLink
- Web of science

##### 3.1.3. Selection of search terms

The key words and phrases extracted from the research questions, which will serve as search terms and search strings are:

- “Quantitative Models” AND “Sustainable Supply Chain”
- “Quantitative Models” AND “Green Supply Chain”
- “Quantitative Models” AND “Sustainable Supply Chain Network design”
- “Implementation” OR “Application AND “Quantitative Models” AND “Sustainable Supply Chain”

### 3.1.4. Application of practical inclusion and exclusion criteria

The inclusion criteria that have been defined are:

- Articles written in English language
- Articles published in a peer-reviewed journals
- Articles published between January 2010 and February 2020
- Studies based on a set of strategies that obtain and process information using statistics and numerical techniques

On the other hand, the exclusion criteria to be considered are:

- Duplicity
- Articles focusing on CLSC, remanufacturing or reverse logistics
- Empirical studies and conceptual models

### 3.2. Descriptive analysis

Once the steps for collecting the different articles have been established, the descriptive analysis is responsible for analyzing the time and journals in which they have been published, by means of a temporal distribution over the study horizon and a 4W analysis (when, who, what and where).

To perform the 4W analysis and answer these questions, the articles (when) are divided by year of publication, (Who) the journals where the different articles have been published are identified, (What) the quantitative models applied in SSC are analyzed, Finally, (where) the institutions to which the researchers belong and their host country are identified.

### 3.3. Category identification

In this section, three structural dimensions are defined and grouped by category: SCM, modeling and sustainability. These will provide a comprehensive and deep understanding of how quantitative models have been used in forward SC, how they have supported sustainability decisions and which are the main sustainability pillars used.

The dimensions of the first category, SCM, are taken from the “Supply Chain Operations Reference” (SCOR) model [36]. The modeling category is evaluated according to the purpose and type of the model. And the last category, sustainability, its classification is based on the three pillars established in the “triple bottom line” concept, which are environmental, economic and social.

### 3.4. Material evaluation

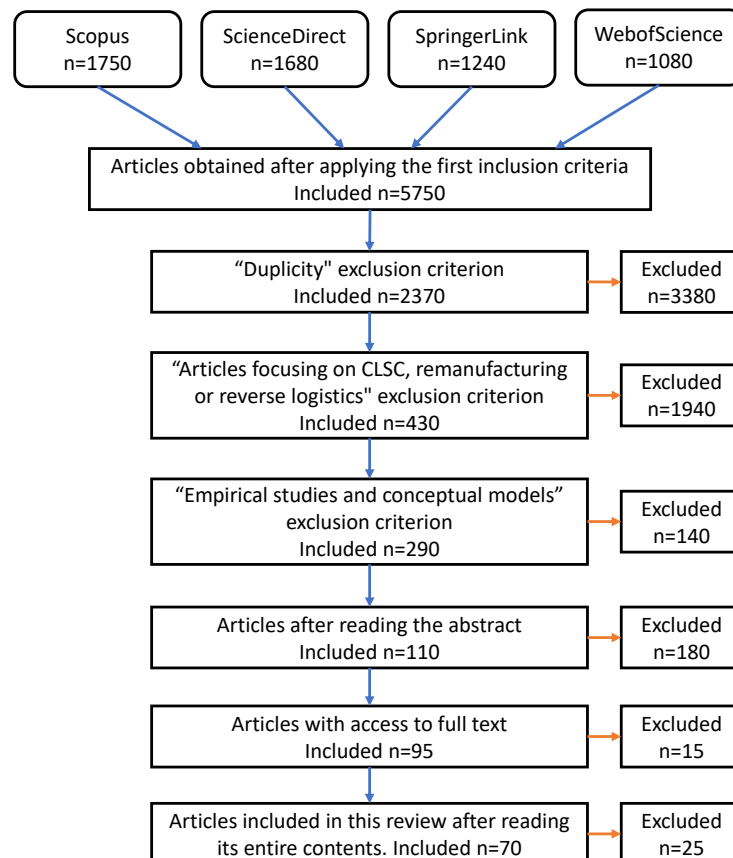
In this step the collected items are coded according to the dimensions of each category described in Section 3.3. This allows reflecting the SC structure, the modeling dimension and their interaction to manage sustainability results.

Subsequently, frequency of occurrence tables are produced, which are the basis for the content analysis, as they allow identifying dominant characteristics and gaps in existing research that can guide future studies. In general, the research process is documented step-by-step in a clear and transparent manner to increase its objectivity.

## 4. Results

### 4.1. Material collection

The steps of the selection process and the associated paper counts have been summarized in Figure 1 allowing to visualize them in a global way.



**Figure 1.** Diagram of material collection.

After rigorously following all the established steps to ensure the quality and objectivity of our work, we have obtained 70 articles, which represent the sample of our systematic literature review.

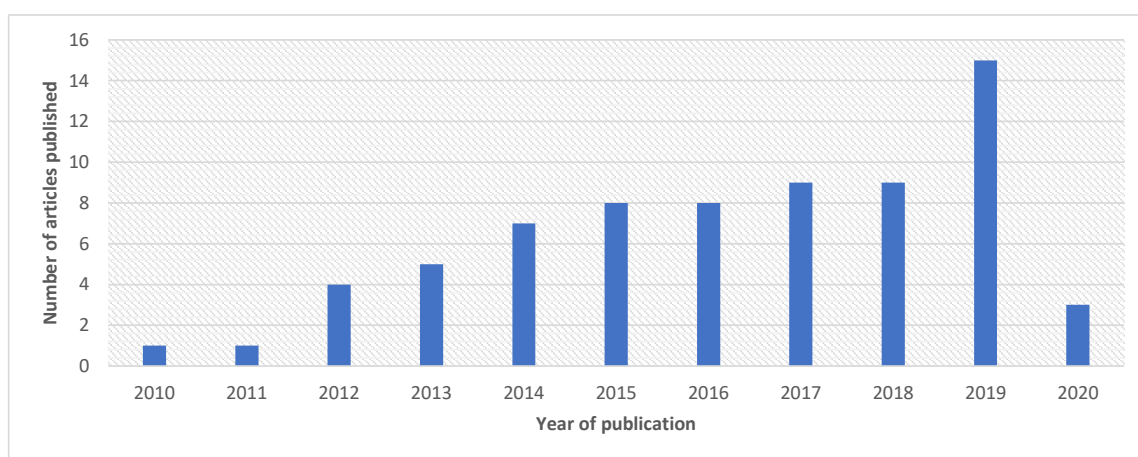
### 4.2. Descriptive analysis

In order to answer the 4W analysis proposed in Section 3.2 of the methodology, we start with the "When" field, for which we use a time distribution in Figure 2, where we observe the number of articles published in the different years analyzed in our sample. There is an upward trend as the years progress, with a direct relationship between the variables, years and the number of articles published. Most of the publications occurred in 2019 (fifteen), and despite the short time elapsed in 2020 (February), there are already 3 publications.

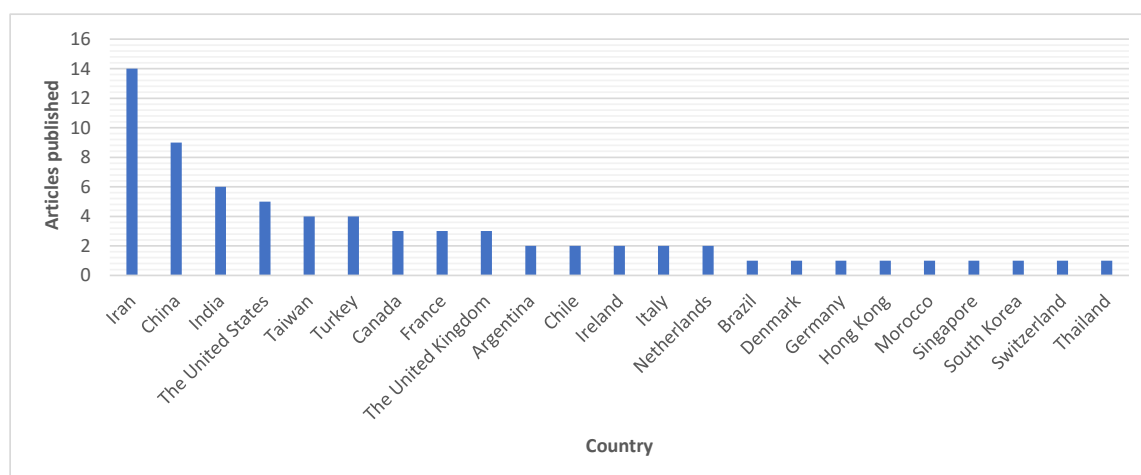
**Table 1.** Distribution of papers by journal.

Journal	Papers	Quantitative Model Type
Computers and Industrial Engineering	9	Heuristics (2), Hybrid (1), Mathematical programming (6)
International Journal of Production Economics	7	Analytical (1), Mathematical programming (5), Simulation (1)
Journal of Cleaner Production	7	Analytical (1), Mathematical programming (6)
Computers and Operations Research	4	Analytical (1), Hybrid (1), Mathematical programming (2)
European Journal of Operational Research	4	Analytical (2), Mathematical programming (2)
Annals of Operations Research	3	Mathematical programming (2), Simulation (1)
Clean Technologies and Environmental Policy	2	Mathematical programming (1), Various (1)
Energy	2	Mathematical programming (2)
Journal of Manufacturing Technology Management	2	Analytical (1), Mathematical programming (1)
Transportation Research Part D	2	Analytical, Heuristics (1)
Transportation Research Part E	2	Mathematical programming (2)
American Institute of Chemical Engineers Journal	1	Mathematical programming
Biomass and Bioenergy	1	Mathematical programming
Biomass Conversion and Biorefinery	1	Mathematical programming
Canadian Journal of Forest Research	1	Simulation
Chaos, Solitons and Fractals	1	Mathematical programming
Computational Economics	1	Mathematical programming
Computer Aided Chemical Engineering	1	Simulation
Environmental Technology	1	Mathematical programming
Global Journal of Flexible Systems Management	1	Analytical
IFAC Proceedings Volumes	1	Heuristics
Industrial and Engineering Chemistry Research	1	Mathematical programming
Industrial Management and Data Systems	1	Analytical
Int. Journal of Industrial Engineering Computations	1	Mathematical programming
Int. Journal of Production Research	1	Analytical
Journal of Intelligent and Fuzzy Systems	1	Mathematical programming
Journal of Intelligent Manufacturing	1	Heuristics
Journal of the Transportation Research Board	1	Mathematical programming
Management of Environmental Quality	1	Analytical
Mathematical Problems in Engineering	1	Mathematical programming
Operational Research	1	Analytical
Renewable and Sustainable Energy Reviews	1	Mathematical programming
Scientia Iranica	1	Hybrid
SpringerPlus	1	Analytical
Sustainability	1	Mathematical programming
Sustainable Energy Technologies and Assessments	1	Mathematical programming
Sustainable Production and Consumption	1	Various





**Figure 2.** Time distribution of reference papers.



**Figure 3.** Distribution of the selected papers by country.

Regarding the “Who” field, the articles in the sample have been published by 37 different journals, and only 11 of them have two or more publications. Table 1, shows all the journals in the sample and the number of articles published in each of them in descending order, and also includes a column indicating the types of quantitative models that have been applied and can be found in each journal, in response to the “What” analysis.

According to Table 1, the journals with the highest number of publications are: Computers and Industrial Engineering (9 papers) tops the list. International Journal of Production Economics (7). Journal of Cleaner Production (7). Computers and Operations Research (4). European Journal of Operational Research (4). Annals of Operations Research (3). Clean Technologies and Environmental Policy (2). Energy (2). Journal of Manufacturing Technology Management (2). Transportation Research Part D (2). Transportation Research Part E (2). The others with 1 each one follow.

As evidenced in the summary Table 1, SSCM-related research has been published in journals from diverse knowledge areas and topics, some with a specific focus on SC and operations management and others general and interdisciplinary. Demonstrating once again its growing boom.

Regarding the types of quantitative models applied, it can be concluded that mathematical programming model, is the most used (43 papers), followed by Analytical (13), Heuristics (5), Simulation (4), Hybrid (3) and Various (2).

Finally, the “Where” field is answered with the analysis of the geographical origin of the sample, i.e., the country of the institution associated with the researcher. Figure 3 indicates that there are 23 countries, being those with the highest scientific production: Iran (14 papers), China (9), India (6), The United States of America (5), Taiwan (4), Turkey (4), Canada (3) France (3) and The United Kingdom (3).

#### 4.3. SCM dimension

The results of the first SCM dimension of the category identification section are presented in Table 2, detailing the absolute frequencies of four characteristics analyzed in each sample study: primary actor, organizational level, SCOR process and application area.

**Table 2.** Frequencies of the SCM dimension.

Primary Actor		Level		Process		Functional Application Area	
Distributor	2	Chain	8	Deliver	5	Logistics	7
Industry / Macro-econ	22	Firm	11	Make	10	Network design	26
Manufacturer	42	Function	11	Plan	45	Planning	1
Retailer	2	Industry	9	Source	5	Production	6
Supplier	1	Macro-economy	5	Various*	5	SCM	28
Warehousing	1	Network	26			Sourcing	2
Total	70	Total	70	Total	70	Total	70

\*Various, refers to the fact that the study covers more than one particular process.

Approximately sixty percent (42 papers) of the reviewed material concentrate its study on manufacturers as the primary actor in planned SC, followed by industry/macroeconomics (22 papers), while distributors [37, 38], retailers [39, 40], suppliers [41] and warehousing [42] are seldom the focus of these studies. The primary actor of the analysis for our purpose is the subject who makes decisions, generates policies and procedures for the use of the quantitative models presented in the sample.

The level of organizational analysis shows a tendency for the inter-organizational perspective with 34 papers between chain and network, followed by intra-organizational models with 22 papers considering a specific function or company, and finally a macroscopic perspective comprising 14 articles between industry and macro-economy. The two most popular SCOR process are planning (45 papers) and make (10 papers).

As for the functional application area, SSCM modeling research targets general SCM (28 papers) or Network design (26 papers), the latter being apparently a new trend in SSCM research that is gaining strength over time, because from 2015 to the present there have been at least three publications per year, showing continuity, superiority and a slight increase compared to other areas.

#### 4.4. Modeling dimension

As part of the category identification, Table 3, provides an overview of the modeling dimension of the sample, where four categories are analyzed: (1) Model data, (2) Model type, (3) Modeling technique and (4) Solution approach.

**Table 3.** Frequencies of the Modeling dimension.

Model Data		Model Type		Modeling Technique		Solution Approach	
Deterministic	42	Analytical	13	MCDM	4	AHP	13
Stochastic	28	Heuristics	5	Metaheuristic	2	DEA / IOA	2
		Hybrid	3	Multi-Objective	29	Fuzzy Program.	6
		Mathematical Prog.	43	Single-Objective	4	Genetic Algorithm	2
		Simulation	4	System Dynamics	2	Goal Program.	2
		Various*	2	Systemic Model	9	LP/MILP	17
				Various*	20	LCA	3
						Nonlinear Program.	5
						Robust Optimization	5
						Stochastic Program.	8
						Various*	7
Total	70	Total	70	Total	70	Total	70

\*Various, refers to the fact that the model is composed of more than one category.

In the model data category, deterministic studies prevail with 60 (42 papers) compared to 40% (28 papers) stochastic studies, that is, in most articles the typical uncertainty of some variables is not considered. Regarding the modeling technique, it can be concluded that the multi-objective optimization technique is the most common (29 papers), although it is part of the multiple criteria decision making (MCDM) technique, we wanted to give it a particular space due to the number of papers found and its usefulness in generating a range of optimal solutions, which are considered equally good, such as [43]. On the other hand, the MCDM technique, which includes the rest of the models that do not use multi-objective optimization in their approach or resolution, contains 4 papers, as [40].

In addition, a considerable number of papers use more than one modeling technique (20 papers) for example [44]. This is because sustainability problems integrate multiple variables and factors. Some authors propose a hybrid model, which includes a multi-objective metaheuristic technique to integrate sustainable order allocation [45].

In the solution approach category, we can highlight the following: the Analytical and Systemic models mainly employ analytic hierarchy process (AHP) (13 papers) or inputoutput-analysis (IOA) (2 papers). The mathematical programming models deterministic usually use linear programming (LP) [46], mixed integer linear programming (MILP) [47] or e-constraint method [48] (17 papers in total). On the other hand, the mathematical programming models with stochastic data, to be able to lead with uncertainty, they use Stochastic Programming (8 papers) [49], Fuzzy Programming (6 papers) [50] and to a lesser extent Robust optimization (5 papers).

Stochastic models in recent years have increased their scientific output and have focused on solving

practical problems of the manufacturer such as: aggregate production planning considering flexible lead times [51], handling market uncertainties and different risk attitudes [52], and production planning with stochastic demands and carbon variables [53].

In terms of industry, it can be seen that the models focused on the bio-fuels [11, 47, 54] and agriculture [55] sectors stand out, in which, through the design of their supply chains, they seek to implement sustainability measures while guaranteeing the level of production. The absence of research related to transportation is also noteworthy, due to its high contribution to greenhouse gas emissions.

To finish the modeling dimension, Table 4, illustrates in detail the models used in each of the 70 papers of the sample.

**Table 4.** Modeling dimension by paper.

#	Paper	Model purpose	Model type	Modeling technique	Solution approach
1	[48]	Deterministic	Mathematical programming	Multi-objective	LP, Augmented e-constraint method
2	[56]	Stochastic	Mathematical programming	Multi-objective	MILP, Augmented e-constraint method
3	[57]	Deterministic	Mathematical programming	Multi-objective	Conventional e-constraint method
4	[58]	Deterministic	Mathematical programming	Multi-objective	MILP, Conventional e-constraint method
5	[59]	Deterministic	Mathematical programming	Multi-objective	MILP, Augmented e-constraint method
6	[17]	Deterministic	Mathematical programming	Multi-objective	MILP, Conventional e-constraint method
7	[60]	Deterministic	Mathematical programming	Multi-objective	Conventional e-constraint method
8	[61]	Deterministic	Mathematical programming	Multi-objective	MILP, Conventional e-constraint, LCA
9	[46]	Deterministic	Mathematical programming	Multi-objective	LP, Conventional e-constraint method
10	[62]	Deterministic	Mathematical programming	Multi-objective	Conventional e-constraint method
11	[63]	Stochastic	Mathematical programming	Multi-objective	MILP, Stochastic P.
12	[44]	Stochastic	Mathematical programming	Multi-objective	MILP, Stochastic P.
13	[64]	Stochastic	Mathematical programming	Multi-objective	Multi-stage Stochastic P.
14	[51]	Stochastic	Mathematical programming	Various	Stochastic Nonlinear MIP

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#	Paper	Model purpose	Model type	Modeling technique	Solution approach
15	[49]	Stochastic	Mathematical programming	Chance constrained	Stochastic P., Benders decomposition
16	[65]	Stochastic	Mathematical programming	Various	Multi-stage stochastic dynamic P.
17	[54]	Stochastic	Mathematical programming	Various	Two-stage stochastic P., Lagrange relaxation
18	[66]	Stochastic	Mathematical programming	Multi-objective	Fuzzy-Stochastic P.
19	[67]	Deterministic	Mathematical programming	Multi-objective	Fuzzy Goal P.
20	[68]	Stochastic	Mathematical programming	Multi-objective	Fuzzy e-constraint P.
21	[50]	Stochastic	Mathematical programming	Multi-objective	LP, Fuzzy e-constraint, Goal P.
22	[69]	Stochastic	Mathematical programming	Multi-objective	Fuzzy MILP, Goal P.
23	[70]	Stochastic	Mathematical programming	Multi-objective	Fuzzy P., Benders decomposition
24	[11]	Stochastic	Mathematical programming	Multi-objective	Robust possibilistic MILP
25	[52]	Stochastic	Mathematical programming	Multi-objective	Robust, Conventional e-constraint
26	[71]	Stochastic	Mathematical programming	Multi-objective	MILP, Robust optimization
27	[72]	Stochastic	Mathematical programming	Bi-level programming	LP, MILP, Robust optimization
28	[73]	Stochastic	Mathematical programming	Bi-level programming	MILP, Robust optimization, Fuzzy P.
29	[74]	Stochastic	Mathematical programming	Multi-objective	AHP, Robust optimization, Nonlinear P.
30	[3]	Deterministic	Mathematical programming	Multi-objective	MILP, two-phase
31	[75]	Deterministic	Mathematical programming	Multi-objective	MILP, LCA
32	[43]	Deterministic	Mathematical programming	Multi-objective	Nonlinear MIP, Genetic algorithm
33	[76]	Deterministic	Mathematical programming	Multi-objective	Weighted sum model, AHP

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#	Paper	Model purpose	Model type	Modeling technique	Solution approach
34	[47]	Deterministic	Mathematical programming	Multi-objective	MILP
35	[55]	Deterministic	Mathematical programming	MCDM	MILP, AHP
36	[77]	Stochastic	Mathematical programming	MCDM	MILP, LCA
37	[78]	Deterministic	Mathematical programming	Various	MILP
38	[79]	Deterministic	Mathematical programming	Various	Speculation-postponement strategy
39	[80]	Stochastic	Mathematical programming	Various	LP, Chance-constrained, Two-stage DEA model
40	[53]	Stochastic	Mathematical programming	Single-objective	Two-stage Stochastic P
41	[39]	Deterministic	Mathematical programming	Single-objective	Goal P.
42	[81]	Stochastic	Mathematical programming	Single-objective	Chance constrained P.
43	[82]	Deterministic	Mathematical programming	Single-objective	MILP
44	[42]	Deterministic	Heuristics	Multi-objective, Metaheuristic	Genetic algorithm
45	[6]	Deterministic	Heuristics	Metaheuristic	MILP
46	[83]	Deterministic	Heuristics	Metaheuristic	Nonlinear MIP, Genetic algorithm
47	[84]	Deterministic	Heuristics	Multi-objective	Nonlinear MIP
48	[85]	Deterministic	Heuristics	Lagrangian relaxtion	LP
49	[45]	Stochastic	Hybrid	Multi-objective, Metaheuristic	AHP, ANP, DEA, MILP
50	[86]	Deterministic	Hybrid	Multi-objective	Hybrid genetic Taguchi algorithm
51	[87]	Stochastic	Hybrid	Fuzzy MCMD	AHP, VIKOR
52	[88]	Deterministic	Simulation	System Dynamics	Nonlinear Dynamics System
53	[89]	Deterministic	Simulation	System Dynamics	Nonlinear Dynamics System
54	[90]	Deterministic	Simulation	Various	LCA
55	[38]	Deterministic	Simulation	Various	Extendend Goal P.

Continue on the next page.

#	Paper	Model purpose	Model type	Modeling technique	Solution approach
56	[14]	Deterministic	Analytical, Math. P.	Systemic model, Multi-objective	AHP, Augmented e-constraint
57	[91]	Stochastic	Analytical, Math. P.	Systemic model, Fuzzy-TOPSIS	AHP, Chance Constrained P.
58	[92]	Deterministic	Analytical	MCDM	AHP, Fuzzy, ILP
59	[40]	Deterministic	Analytical	MCMD	AHP, Fuzzy
60	[93]	Stochastic	Analytical	MCDM, Systemic model	Grey relational analysis, Fuzzy
61	[94]	Deterministic	Analytical	Systemic model	AHP, Input-Output-based Life Cycle Assessment
62	[95]	Stochastic	Analytical	Systemic model	AHP
63	[37]	Deterministic	Analytical	Systemic model	AHP, Genetic algorithm
64	[41]	Deterministic	Analytical	Systemic model	Multi-Agent, Fuzzy Inference System
65	[21]	Deterministic	Analytical	Systemic model	AHP, QFD
66	[96]	Deterministic	Analytical	Systemic model	IOA
67	[97]	Deterministic	Analytical	Systemic model	DEA
68	[98]	Deterministic	Analytical	Systemic model	AHP
69	[99]	Deterministic	Analytical	Systemic model	AHP, Genetic
70	[100]	Deterministic	Analytical	Systemic model	AHP, Fuzzy

#### 4.5. Sustainability dimension

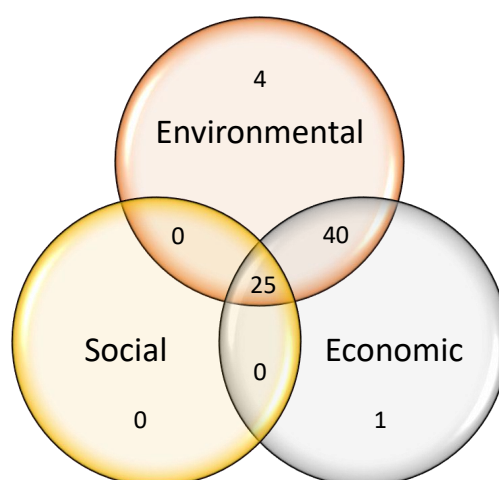
The dimensions of the sustainability distributed in the studied sample can be seen in Figure 4. Four investigations focus exclusively on environmental needs, analyzing environmental parameters and carbon emissions, like [99]. Forty papers consider economic-environmental performance focusing on the study of greenhouse emissions (GHG) [63], Carbon Emissions [55], Life cycle analysis (LCA) [75], Amount of waste biomass [69], Energy [79], nitrogen dioxide NO<sub>2</sub> [58], water and solid waste [90]. Finally, twenty-five articles develop SSCM models that consider the three dimensions of sustainability. As for the variables related to the social factor, the following stand out: population, training, noise, wages, job creation, occupational health and safety [40, 52, 81].

#### 4.6. Research gaps and future research perspectives

As part of the results of the systematic literature review developed throughout this study, we propose four ideas that explain the research gaps and future research prospects. These ideas may be useful in the academic or research area, and will provide an overview for all stakeholders interested in the implementation and development of sustainability in their organizations.

First, a lack of industry focus is evident in the analyzed models of the sample, since around thirty percent of the sample (22 papers) does not apply their research in a particular sector, they only do it in a generic and empirical way. The industries most studied are bio-fuel and related products (15 papers),

Agriculture (5 papers) and food (4 papers). There is a need to consider applications in sectors like medical, automotive, chemical and textile, they only have a total of 7 papers.



**Figure 4.** Distribution of reference papers with respect to the three sustainability dimensions.

Second, while it is true that the concept of a product's life cycle is frequently used in supply chains and their operations, the environmental impacts they generate estimated through an LCA are not considered in the construction of any quantitative model of the sample, then including LCA in the design of SSC is a challenge that so far has not been fully developed.

Third, regarding the SSCM risk model, the findings confirm the predominance of economic variables, followed by environmental and, to a lesser extent, social variables. In addition, 60% of the quantitative models do not consider the implicit uncertainty of these variables and the risks they entail. Future research that analyzes the behavior of the model as a function of changes in its parameters should consider the explicit evaluation of the uncertainty in the variables, which would provide tools that are close to reality and would allow us to satisfy current needs.

Fourth, from the data acquired from the sample, the most studied dimensions of sustainability are the economic-environmental dimension; the social dimension has not yet been exploited but has already taken its first steps, since in recent years there has been a considerable increase in studies that consider the concept of the “triple bottom line”, and this is the line to be followed by researchers. Considering economic, environmental and social variables guarantees optimal development and implementation of sustainability in today's supply chains.

## 5. Discussion

Today's markets are increasingly dynamic, forcing companies to constantly reinvent themselves so as not to stagnate in the past [2], and they are obliged to know exactly the factors influencing their SC that they will have to work on to ensure their success. There are structural, operational design, technological, resource management, environmental and economic factors [4]. Quantitative SC models then attempt to include one or more of these factors to support business management and decision making.



The selection of a particular model depends exclusively on the needs of each company, which are influenced by the respective industrial context, for example from what we have observed in the SCM dimension and the modeling dimension, we can say that managerial decisions are often supported by optimization methods, while in macroscopic contexts, models are more frequently used to analyze and explain the behavior and interaction of variables.

In several studies in our sample, it is observed that sustainability aspects to be considered are used as a moderating variable driving the purpose of modeling. Current research focuses on production processes and their respective environmental impacts, there is talk about improvements in planning and green chain initiatives, but there has not yet been a deepening of research into new production processes, machine design, interface between actors, which would reduce these unsustainable sources.

Finally, it is necessary to expand research focused on critical industries such as transportation, chemicals and textiles, which stand out for their environmental and social impact problems.

## 6. Conclusions

The main objective of our study has been met through the development of a systematic literature review, in which 70 papers were identified and critically, systematically, transparently and reproducibly evaluated. Therefore, data concerning SSCM were collected and analyzed that provided a synthesis of the key elements of quantitative model offerings that use sustainability indicators in the design and management of forward SC.

The sample analysis evidences that research on quantitative modeling applied in SSC has increased its production continuously since 2012, driven by factors such as scarcity of natural resources, global warming, governmental agreements and policies, and above all the search for competitive advantages to attract environmentally friendly customers. Companies and organizations can find in the literature multiple types of quantitative models, studies like this one, help them to focus on the right set of models for their needs, the selection of the final model will depend on the actors involved and its adaptability in the current SC.

The findings show that deterministic models are the most popular in SSCM, evidencing the need for more stochastic approaches in modeling to relay a more realistic uncertain decision environment. Other future research directions that were analyzed through the gaps found include a greater focus and scope on modeling in the industry, the integration of LCA in a SSCN design and to consider in greater measure social risk factors into modeling.

Finally, regarding the limitations of the study, we can say that one of them is the type of literature review used, since the systematic review is generally limited to collecting and analyzing research data, unlike the integrative review, which evaluates, criticizes and synthesizes the literature to enhance the emergence of new theoretical frameworks and perspectives [101]. Other limitation was the subjectivity with which the content of the sample was analyzed, which depends to a great extent on the knowledge, judgment, experience and number of researchers involved. On the other hand, despite having followed the methodologies of authors such as [27] and [35], the sample obtained is limited to the search keywords and databases used. Overcoming these details, we are sure that this work will serve as a decision support tool for all those who wish to incur, study, investigate and implement sustainability in SC.

## Conflict of interest

The authors declare no conflict of interest.

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